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Comparing the Non-Invasive Cardiometry with Ultrasound Guided Inferior Vena Cava Collapsibility for Evaluation of Fluid Responsiveness in Septic Patient, Randomized Clinical Trial

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Abstract

Background: Reliability and comparability to cardiometry-estimated stroke volume fluctuation have been shown for ultrasound-guided IVC diameter variation with respiration as a predictor of volume responsiveness. The repeatability and low inter-operator variability of intravascular ultrasonography make it an ideal tool for reassessing intravascular volume after the delivery or removal of volume. Electrical cardiometry (EC) uses four skin electrodes to assess changes in thoracic impedance or resistance. EC is able to separate the impedance variations that occur during the cardiac cycle. In order to better treat critically sick septic patients with hemodynamic instability, this review paper seeks to evaluate the accuracy of fluid responsiveness evaluation using non-invasive cardiometry to ultrasound guided IVC collapsibility. In summary: Patients experiencing septic shock were more likely to have a poor prognosis if their fluid balance was positive. When evaluating the intravascular volume state of critically ill patients, the inferior vena cava collapsibility index may provide useful recommendations without invasive procedures. Fluid management decisions in severely sick patients may benefit from advanced hemodynamic monitoring using EC. If EC can continue to track CO trends, it might be useful for clinical decision-making in identifying sudden shifts in the gas. Since EC is non-toxic and simple to implement, this should form a significant portion of future studies.

Key words: Non-Invasive Cardiometry, Ultrasound-Guided, Inferior Vena Cava Collapsibility, Fluid Responsiveness, Septic Patient.

1.Introduction

When microbes invade the body, it triggers a cascade of inflammatory mediators such cytokines and interleukins, leading to sepsis, a systemic sickness. Systems inflammatory response syndrome (SIRS) starts with these markers [23].

Severe sepsis patients run the danger of experiencing abrupt hemodynamic instability, which may have devastating effects on their health. Cardiac contractile dysfunction and unopposed heterogonous vasodilatation are symptoms of sepsis. An important part of treating acute circulatory failure and its complications is the use of fluid therapy [16].

The first line of defense against hypotension and hypoperfusion caused by sepsis is intravenous fluid resuscitation. In a shock situation, the goal is to maximize cardiac output while simultaneously restoring circulation volume [36].

Septic shock-induced hypotension is best treated with fluid resuscitation and vasopressor therapy, which work together to restore normal vascular tone and increase organ perfusion pressure. Regarding septic shock, the current consensus among experts is that norepinephrine (NE) should be administered as a first-line vasopressor. Despite encouraging early findings, vasopressin and its analogues are now considered second-line vasopressors due to significant new evidence that they do not benefit from early administration [29].

In order to maximize organ perfusion and resuscitation, there should be accurate predictors of fluid response and a way to identify patients who require inotropes or vasopressors early enough [18].

The point-of-care ultrasound (POCUS) measurement of inferior vena cava (IVC) collapsibility is useful for identifying critically sick patients who react to fluids and those who do not, and it may also be used to direct fluid resuscitation in patients who are breathing on their own[13] .

This shift in electrical conductivity is tracked by the electrical cardiometry (EC) monitor. The EC monitor calculates key metrics such cardiac index (CI), stroke volume (SV), peak aortic acceleration, and left ventricle ejection time using proprietary algorithms. Research on the accuracy of EC in detecting absolute levels of SV is inconsistent, while it has shown usefulness in monitoring cardiac output (CO) across a variety of patient situations and populations[6].

A patient's fluid status may now be determined by measuring the internal venous diameter (IVC) and how it varies throughout breathing using ultrasonography as a reference. It's an affordable method that is also safe. As an alternate to central venous catheterization, it is often used to assess patients' volume status (figure 1-A). During the first half of the ascent, even a slight change in CVP causes an increase in IVC diameter. Part 2 shows a decline in IVC compliance and a small rise in IVC dilatation brought on by a bigger increase in CVP. Updated from Figure 1 (B), which shows the relationship between cardiac functional reserve and inferior vena cava diameter. Subjects with normal cardiac function (solid lines) and impaired cardiac function (dotted lines) had their venous return and cardiac function curves intersected. Inspiration can only cause a leftward shift in the cardiac function curve, resulting in a decrease in CVP and an improvement in IVC collapse, if cardiac function is maintained. Because it accounts for the variations in volume that occur while breathing, it provides a living indicator of the state of intravascular volume [20].

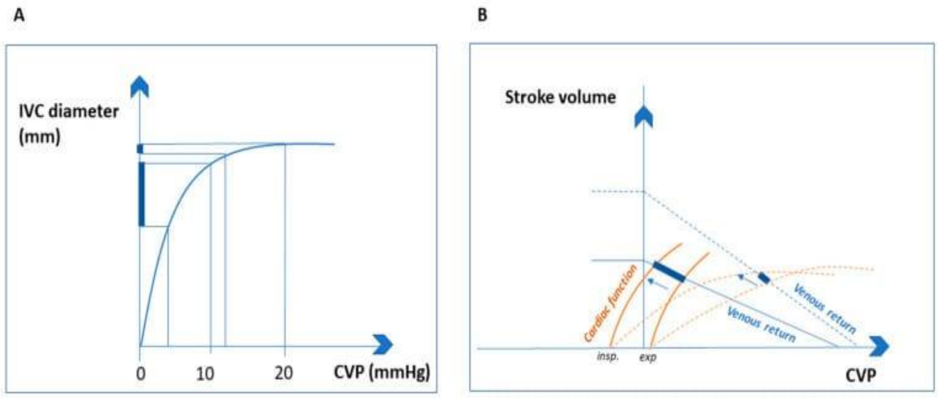

Fig. (1) (A) Relationship between residual venous compliance and inferior vena cava diameter (B) the relationship between the central venous pressure (CVP) and the residual venous compliance (IVC) and the fluctuations in stroke volume. According to [25].

In Especially in intensive care units, this rapid, non-invasive assessment of IVC is crucial. Cardiogenic shock, septic shock, and hypovolemic shock might all be distinguished using this. The volume status may be revealed by variations in the diameter of the inferior vena cava (IVC)[22].

The purpose of this research was to evaluate the accuracy of non-invasive cardiometry for fluid responsiveness evaluation to that of ultrasound guided IVC collapsibility in the treatment of very sick septic patients with hemodynamic instability.

How the body works:

The study of the movement of blood is known as hemodynamics. Similar to how hydraulic circuits are regulated by control systems, the circulatory system is governed by homeostatic processes of autoregulation. The hemodynamic response is always on the lookout for changes in the body and its surroundings, and it makes adjustments accordingly. The branch of physics known as hemodynamics describes the rules that regulate the movement of blood through the circulatory system [43].

A resting heart rate of 5 to 6 liters per minute is considered normal. No blood leaves the heart just because it enters the left ventricle. According to[1], the end systolic volume (ESV) is the result of subtracting the stroke volume from the remaining end diastolic volume (EDV).

Vascular monitoring

Acute care patient monitoring revolves on hemodynamic monitoring. Patients at high risk for problems and prolonged hospital stays are better served by goal-directed treatment. Cardiovascular insufficiency (CVI) resuscitation treatment strategies tailored to individual patients. Some of these methods include reducing the amount of time a patient spends in the hospital, using dynamic measurements to determine vasomotor tone and volume responsiveness, and reducing the amount of fluid and vasopressor time that patients need. Hemodynamic monitoring with the purpose of predicting future CVI by the use of machine learning techniques. against the moment, these methods are aimed against anticipated hypotension [12].

When used with clinical evaluation to determine perfusion adequacy, hemodynamic monitoring methods may detect cardiovascular insufficiency (CVI) and provide individualized hemodynamic treatments. Better results should be accompanied by effective hemodynamic monitoring in order to accomplish these objectives. However, without a suitable and efficient therapy, no hemodynamic monitoring technology can enhance results[21] Figure 1

Table (1) Acute care outcomes intended to be achieved by hemodynamic monitoring

Setting	**Monitor-treatment**	**Outcome**
Perioperative	Pre-optimization (CO)	Reduced complications
		Reduced ventilator time
		Reduced ICU/hospital length of stay (LOS)
	Functional hemodynamic monitoring	Decreased infused volume
		Decreased lac-time
	Hypotension prediction	Decreased hypotension time
Emergency Department	Sepsis resuscitation SSG	Decreased mortality
	Functional hemodynamic monitoring sepsis	Decreased infused volume
		Lower lac-time
		Decrease hypotension time
ICU resuscitation	Functional hemodynamic monitoring sepsis	Decreased infused volume
		Decreased hypotension time
ICU management	Stabilization/de-escalation (Eadyn)	Rapid norepinephrine weaning

2.Electric Cardiometry:

Electrical cardiometry uses four surface electrocardiogram (ECG) electrodes to non-invasively measure hemodynamic parameters such as cardiac output (CO), stroke volume (SV), and others, and is based on the Electrical Velocimetry model. The Cardiotronic, Inc. patented technique of electrical cardiometry has been cleared for use on neonates, children, and adults by the U.S. Food and Drug Administration [33].

This technique employs an algorithm to determine the CO based on changes in thoracic resistance caused by variations in blood velocity during the cardiac cycle. There have been updates to the algorithm. Most recently, a modification known as electrical cardiometry (EC) was implemented [8].

The quality of the measured signal may be evaluated by the device using its internal quality score. In order for these metrics to be used for clinical decision making, the so-called Signal Quality Indicator (SQI) has to be at least 80. EC is just as accurate and precise as other less intrusive measuring instruments, and it's as safe to use [42].

Two ECG electrodes are placed to the left side of the neck and two are affixed to the lower thorax; this is necessary for the electrical cardiometry procedure. The two external electrodes provide a steady-state alternating current (AC) to the chest, targeting the aortas (both ascending and descending). Because blood is the thorax's most conductive substance, current is directed toward the aorta. According to[3] , the conductivity (also known as bioimpedance) is determined by recording the ratio of the applied current to the measured voltage.

Both impedance cardiography and electrical cardiometry assess TEB, or thoracic electrical bioimpedance. The techniques used to determine the cause of the dramatic rise in TEB/beat are different [33].

According to the patented EC model, the reason for the noticeable shift in thoracic impedance (or conductivity) at the beginning of each cardiac cycle is the red blood cell (RBC) orientation change caused by pulsatile flow [35].

The time it takes for the left ventricle to expel its contents and the maximum aortic acceleration are both derived using EC technology. A medically-patented method determines stroke volume by using the blood flow velocity, which is obtained from the peak aortic acceleration. To initiate a measurement with an EC monitor, all that is required is the patient's weight, height, age, and gender[8]. This information is shown in Figure 2.

Stroke Figure 3 shows a direct, strong, and statistically significant association between the degree of fluid responsiveness as reported as a percentage increase in cardiac index and pulse pressure variation (PPV) and volume variation (SVV). According to[25] , the only variables that showed a significant difference between the groups of responders and non-responders prior to fluid administration were SVV and PPV.

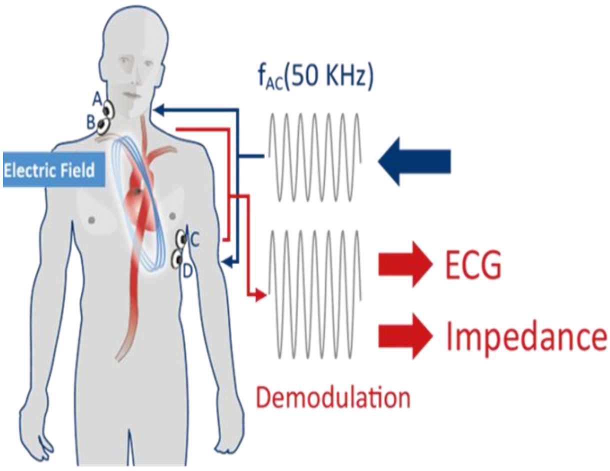

Fig. (2) Scheneck et al., 2020 depicts electrical conduction across electrodes.

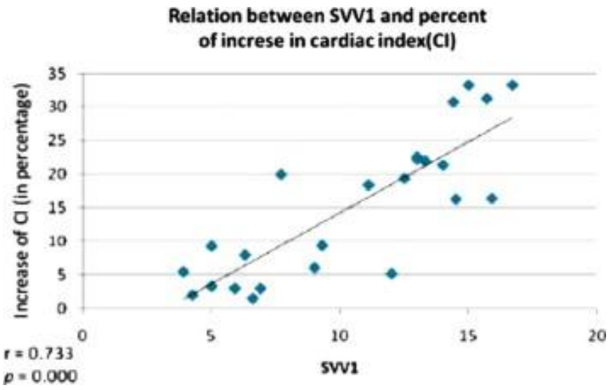

Fig. (3) Correlation between cardiac index CI and stroke volume variation (SVV) According to [25].

3.Role of us guided IVC

A point-of-The supervising physician may use a bedside ultrasonographic evaluation known as a point-of-care ultrasound (POCUS). It offers immediate and accurate solutions to patients' medical issues. Clinicians have increasingly turned to POCUS in recent years, particularly in the ED and ICU. New generations of pediatricians are interested in POCUS use, and there has been a global uptick in POCUS training courses for pediatric Intensive Care Unit and Emergency Room experts [15] . Picture 4

The right atrium of the heart receives deoxygenated blood via the inferior vena cava, a vast vein. Sonographic assessment of the inferior vena cava (IVC) provides a non-invasive, real-time gauge of blood volume status since its dimensions and curvature are associated with central venous pressure and blood volume in circulation. The internal capillary diameter (IVC) fluctuates in relation to variations in intravascular pressure; it is a very flexible conduit. As a result of the negative pressure generated by the expansion of the chest, the inferior vena cava (IVC) collapses during inspiration as blood is pumped out of it. The interventricular septal defect (IVC) narrows by around half in healthy individuals as their thoracic pressure cycles [39].

Despite the absence of agreed-upon thresholds, healthy persons typically have an intercostal diameter (IVC) at rest ranging from 0 to 14 mm for inspiration and 15 to 20 mm for expiratory diameter. The equation (IVCd exp - IVCd insp)/IVCd exp is the IVC collapsible index. As the collapsibility index approaches zero or one hundred percent, the patient is more likely to be experiencing volume excess or depletion, respectively [19].

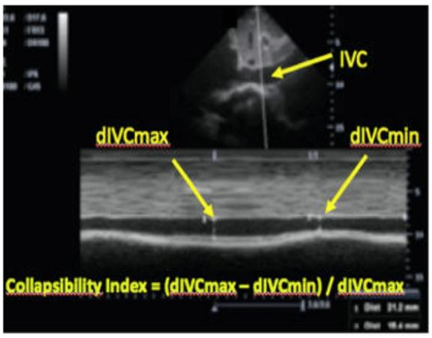

Fig. (4) Obtaining the collapsibility index and measuring the inferior vena cava (IVC) using ultrasound is shown in Figure 4. The two-dimensional image of the inferior vena cava (IVC) with the right atrium shifted to the left may be seen in the panel above, while the M-mode image below reveals fluctuations in diameter due to respiratory factors.[14] defined D IVC max and d IVC min as the maximum and minimum diameters of the inferior vena cava, respectively.

The The inner ventricular canal (IVC) wall is a thin, flexible tube whose width changes in response to the patient's blood volume: During the course of a breath, the inside diameter of the pulmonary veins (IVC) narrows and widens. The IVC momentarily collapses due to the higher blood volume return to the heart caused by the negative pressure created during inhaling. When we breathe out, the IVC narrows back down to its original size since the venous return is reduced [7].

In situations of shock or undifferentiated hypotension, an IVC examination may determine the right-heart pressure and intravascular volume status, which can help with resuscitation. Ultrasound evaluation of the inferior vena cava (IVC) might reveal changes in the patient's volume status. One non-invasive way to estimate the Central Venous

Pressure (CVP) is by measuring the amount to which the inferior vena cava (IVC) collapses during breathing[25].

Evaluating the CVP, which is crucial in undifferentiated shock conditions, is the primary advantage of bedside ultrasonography examination of the IVC. Shock states may cause either a low or high CVP. Hypovolemic shock may be indicated by a small IVC diameter with a high collapsibility index, if the appropriate clinical circumstances are fulfilled. A significant number of IVCs, on the other hand, might point to several causes of shock [32].

[14] noted that patients experiencing shock as a result of cardiogenic failure or obstructive causes, such as pulmonary embolism, cardiac tamponade, constrictive pericarditis, or aortic stenosis, could have a dilated inferior vena cava with little respiratory fluctuation. (Photo 5).

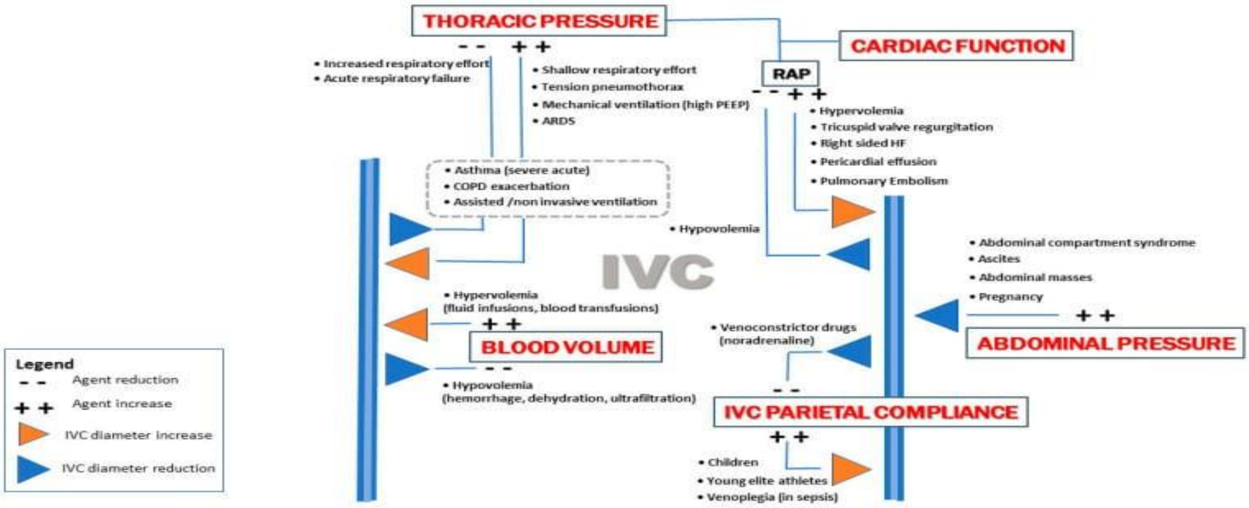

Fig. (5) According to [25], Figure 5 illustrates the main factors that impact the diameter of the inferior vena cava.

4.Discussion

Although CVP evaluation did not predict fluid responsiveness; nevertheless, in the right clinical setting, a tiny, highly collapsible IVC may indicate severe hypovolemia and improve fluid resuscitation. Conversely, acute hypovolemia could not be the reason if a patient in shock has a wide open, non-collapsed IVC [22].

Responsivity of fluids in sepsis

The first line of defense against septic shock is intravenous (IV) fluid resuscitation, with 30 mL/kg of isotonic crystalloid fluid being recommended by worldwide consensus recommendations. The goal is to maximize stroke volume and restore the volume of circulating fluid. Most research are observational or retrospective in nature, hence there is a lack of high-level data to support this method. Recent research has shown that patients with septic shock in critical care who have previously had first resuscitation are more likely to have poor outcomes if their fluid balance is significantly positive [31].

Although randomized studies in low-income countries have shown that increasing the fluid amount delivered during first resuscitation increases mortality among patients with sepsis and hypoperfusion, these results cannot be applied to other contexts. Variation in practice has resulted from this lack of consensus; for example, some have argued for a more cautious fluid approach that includes the early use of vasopressors to provide hemodynamic support. According to [9], there are several current clinical studies that aim to answer this topic.

Fluid response prediction and the importance of intravenous and endovascular monitoring:

Using the IVC diameter in patients on mechanical ventilation is not supported by current research. The association between CVP and IVC diameter was found to be weak to moderate in the other investigations, and not statistically significant in 8 of the 16 research included in the latest meta-analysis. The intricate relationship between intrathoracic pressure, right atrial pressure, and venous return could explain these findings, making it difficult to draw a definitive conclusion in the majority of instances [28].

In order to assess fluid responsiveness, one must take into account the IVC's ability to widen during positive pressure ventilation, changing the steep portion of the IVC-to-CVP curve to a flatter one. In the largest adult population ever studied on this topic, 540 subjects experienced acute circulatory failure of any cause. The results showed that respiratory variations in the IVC diameter failed to accurately predict fluid responsiveness, likely because of concomitant abdominal hypertension and/or a lack of mechanical power during protective mechanical ventilation. This includes factors such as a low tidal volume of less than 8 mL/kg predicted body weight, moderate to low positive end expiratory pressure, a low respiratory rate, and low driving pressures [27].

There is a lack of consistent evidence for pediatric patients using mechanical ventilation. According to [11], the ΔDIVC successfully predicted fluid responsiveness in 21 children who had undergone heart surgery, but it failed to do so in 33 kids who underwent neurosurgical procedures.

Similarly, Weber et al. found that variations in IVC diameter caused by the respiratory cycle were not able to predict fluid responsiveness in their study of 31 participants ranging in age from 1 day to 13 years. Children may have lower transpulmonary pressure because their inferior vena cava (IVC) is more elastic and their chest walls are more flexible than adults' [41].

In subjects who are on mechanical ventilation, Yao and colleagues have introduced a new distensibility index called VCI ADI with a cut-off value of 10.2%. This index outperformed dIVC in terms of sensitivity in predicting fluid responsiveness, despite having a significantly lower specificity (97.3% sensitivity and 40.0% specificity, respectively) [25].

Overall, when it comes to evaluating fluid responsiveness, the IVC collapsibility index is more accurate than the IVC diameter in patients who are breathing on their own. However, its practicality in patients on mechanical ventilation is debatable, and it can only be used when the biventricular heart function is preserved. Furthermore, due to its poor diagnosis accuracy, dIVC is not well-supported by the existing data in the following areas: pediatrics, patients on protective mechanical ventilation, those undergoing abdominal surgery at the same time as hypertension, and those undergoing abdominal surgery[40] .

For goal-directed treatment and clinical decision-making, EC's continuous monitoring might be a useful addition to ICU and NICU monitoring. In a 2015 study, Suehiro et al.

There was a strong connection between the SVV readings obtained by transesophageal echocardiography (TEE) and those obtained by electrical cardiometry, according to a research that compared the two methods. SVV was 15.5% (SD=7.1) after 10 minutes of sternum closure by transesophageal echocardiography (TEE), and 14.3% (SD=6.1) following 10 minutes of sternum closure by cardiometry. A mean bias of -1.2 was found using the Bland-Altman analysis. A range of -8.7% to 5.7% was observed in the 1.96 standard deviations of agreement. It is for this reason that cardiometry has emerged as a viable option for noninvasive hemodynamic monitoring in CABG patients.[38] cited before.

Both before and after surgery, TTE and EC were significantly correlated with respect to HR, SV, SVI, CO, and CI. With widely acknowledged limits of agreement for HR, SV, SVI, CO, and CI, Bland and Altman analysis demonstrated little bias. When comparing EC and TTE, CO demonstrated a robust positive association with a mean bias of 0.01 and limits of agreement ranging from -0.68 to 0.70 for preoperative readings, but a mean bias of -0.01 and limits of agreement ranging from -1.21 to 1.18 for postoperative data.According to [2].

Although EC has the potential to replace Electrocardiography and Thermodilution for measuring absolute CO values, a meta-analysis of 24 studies that compared it to a reference method (Electrocardiography and Thermodilution technique) cast doubt on its accuracy and precision. As The meta-analysis was unable to determine EC's trending ability since the included research did not agree on the statistical approach. However, EC may continue to have use as a trend monitor for acute hemodynamic variability measurements.The cited work is from [17].

5.Conclusions

Positive In septic shock patients, fluid balance was shown to be a significant predictor of poor prognosis. When evaluating the intravascular volume state of critically ill patients, the inferior vena cava collapsibility index may provide useful recommendations without invasive procedures. It is possible to do advanced hemodynamic monitoring using EC while giving critical care. As a result, EC could be a good option to help critically sick patients make decisions about their fluid management. If EC can continue to track CO trends, it might be useful for clinical decision-making in identifying sudden shifts in the gas. Since EC is non-toxic and simple to implement, this should form a significant portion of future studies.

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